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Submarine Base, Groton, Conn.

REPORT NUMBER 685

COMPARISON OF COLOR VISION TESTS USED

BY THE MILITARY SERVICES

by

Helen M. Paulson

Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4305.08-3001DAG9.08

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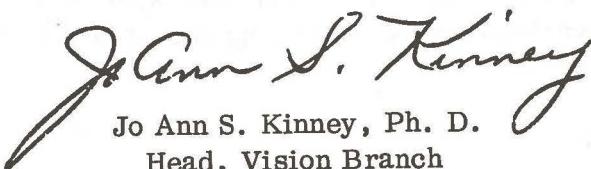
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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
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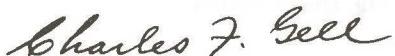
Bureau of Medicine and Surgery, Navy Department
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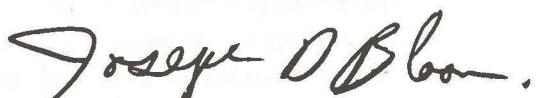
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SUMMARY PAGE

THE PROBLEM

To evaluate and compare the various color vision tests used by the military services and determine the extent to which the different tests select and reject men with the same gradation of color vision defect.

FINDINGS

The six tests evaluated all show some correlation between the degree of color vision defect and the performance score on the test. However, they ranged in their rejection of color defectives from a low of 12% to a high of 94% and men with the same degree of defect have variable chances of being accepted dependent on the test used.

APPLICATION

The results may be used by those establishing standards and recommendations concerning color vision testing within the different Departments of the Armed Forces and other U.S. Agencies. Additionally, those organizations currently revising their color vision standards will find the material of great use.

ADMINISTRATIVE INFORMATION

The investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit M4305.08-3001DAC9 - Development of Visual Screening, Display, and Illumination Standards for Submarine/Shipboard Personnel. The present report is No. 8 on that Work Unit. It was approved for publication on 27 October 1971 and designated as Naval Submarine Medical Research Laboratory Report No. 685.

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ABSTRACT

Color vision tests used by the different Departments and Agencies of the U. S. Government were evaluated and compared. The purpose was to determine the extent to which the different tests select and reject men with the same gradation of color vision defect.

Many color defectives of all types and degrees of defect and a smaller sample of normals were examined on the various tests and the results were compared with the results obtained by these subjects on the Naval Submarine Medical Research Laboratory (NSMRL) Battery of Color Vision Tests for determining type and degree of defect. The NSMRL Battery was described and colorimetric specifications for all the tests used therein are given.

The tests were evaluated individually and comparisons between tests were made. They all showed some correlation between the degree of color vision defect and the performance score on the test. However, they ranged in their rejection of color defectives from a low of 12% to a high of 94%, and men with the same degree of defect have variable chances of being accepted for specific duties dependent on the test used.

and the corresponding precipitation increase is about 10% per degree Celsius. This is consistent with the results of the GCMs, which show a 10% increase in precipitation for a 1°C increase in temperature (IPCC 2001). The projected increase in precipitation is largest over land, particularly in the subtropical continents.

The projected changes in precipitation are also consistent with the results of the GCMs. The projected increase in precipitation is largest over land, particularly in the subtropical continents. The projected decrease in precipitation is largest over the subtropical oceans, particularly in the North Atlantic. The projected decrease in precipitation is also largest over the subtropical continents, particularly in the Northern Hemisphere.

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COMPARISON OF COLOR VISION TESTS USED BY THE MILITARY SERVICES

INTRODUCTION

Each of the Departments of the Armed Forces has specialties within it for which some standard of color vision has been set. For example, men enlisting in the Navy are not disqualified for color vision defects but there are standards for attending Naval Submarine School, electronic school, etc. In fact, half the Naval training schools for enlisted men have a color vision requirement. Similarly, men must meet some minimum requirement of color vision to become a commissioned officer in the Army or a pilot in the Air Force. Obviously, the specific duties performed by men in each of these specialties should determine the color vision standards imposed. Some of these duties are quite similar among different Departments of the Armed Forces and other U.S. Agencies. For example, the duties of pilots - with respect to seeing color - must be similar whether the pilot is a member of the Army, Navy, Air Force, National Aeronautics and Space Administration, or licensed by the Federal Aviation Administration to fly commercial, company, or private planes. Despite the similar duties, each of the various organizations employ different tests of color vision.

This paper reports on the results of testing color defective individuals and a small sample of normals with the various tests currently employed by these different organizations within the government. The purpose was to determine the extent to which the different

tests are selecting and rejecting men with the same gradation of color vision defect. The results should bear on the question of whether color vision testing could be made more uniform for the same specialties within the various organizations.

The five color vision tests used by these Departments and Agencies are the Armed Forces Color Vision Test by American Optical Co., the Dvorine Pseudo-Isochromatic Plates, the Farnsworth Lantern, the Color Threshold Tester, and the Bausch & Lomb Ortho-Rater Color Vision Test Slide No. 71-21-21. In addition, the Model C-11 Colour Perception Lantern, used by the Canadian Armed Forces, was evaluated. Figure 1 shows these six tests.

DESCRIPTION OF THE TESTS

The two sets of plates carried in the Medical Materiel Section of the Federal Supply Catalog for use by all Departments of the Armed Forces are the Armed Forces Color Vision Test by American Optical Company (A.O.) and the Dvorine Pseudo-Isochromatic Plates. Both bear the U.S. Medical Caduceus and the same Federal Stock Number and hence, when an organization orders a set of plates, either set may be issued. Each plate consists of an arrangement of small colored circles. Certain colors are devoted to the background area and other colors are used to form a number. The colors selected for the background circles (yellow-greens, for example) and the number circles (oranges, for example) appear alike to color defectives and

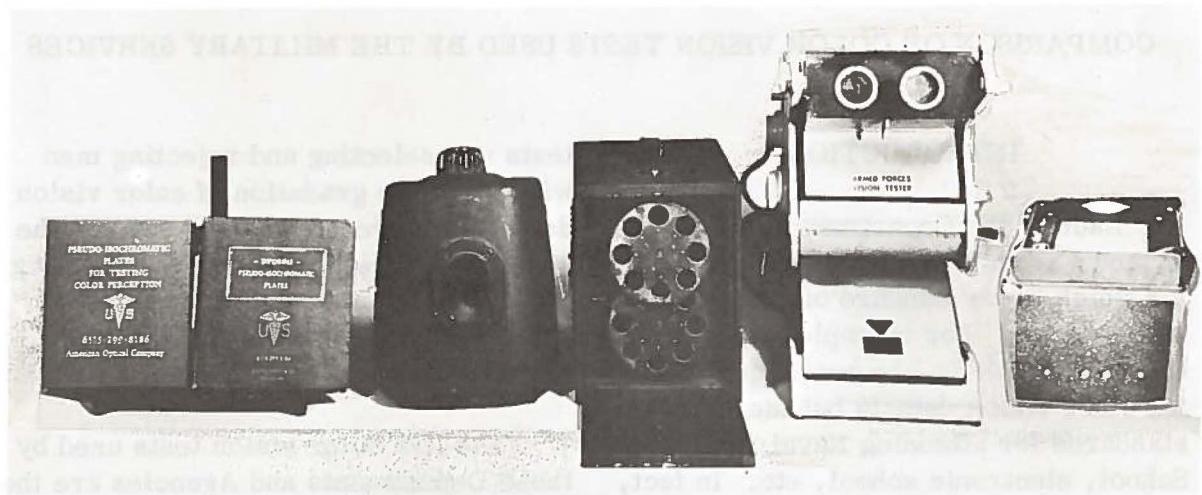


Fig. 1. Color vision tests evaluated - The Armed Forces Selection of American Optical Co. Plates, the Dvorine Plates, the Farnsworth Lantern, the Color Threshold Tester, the Bausch & Lomb Ortho-Rater Color Slide No. 71-21-21, and the Model C-11 Colour Perception Lantern.

hence the number should be invisible to them. Both of these sets of plates consist of a demonstration plate and 14 test plates. Both sets have ring-binders so that the order of the plates may be changed frequently; this counteracts serial memorization by facilitating random order presentation when, as is true most of the time, data sheets are not used.

The A.O. set specifies that the test should be administered at a distance of approximately 30 inches from the examinee's eyes and that about 2 seconds should be allowed for response to each plate, whereas the Dvorine set specifies a distance of 20 to 30 inches and no more than 5 seconds per plate. The A.O. set requires administration under the Daylight Easel Lamp whereas the Dvorine set states that the test shall be administered under any one of the following three illuminants: the

Macbeth Easel Lamp, Daylight Fluorescent Tube, or a 100-watt Blue-Daylight Lamp. Both sets state that 10 or more correct responses to the 14 test plates result in a classification of "Color Vision Normal".

The first set - the A.O. Set - was developed by the Armed Forces-NRC Vision Committee, as is stated in the Federal Supply Catalog. Six of the 14 test plates in this A.O. set are reversible-number plates designed so that a normal sees one number and a color defective sees another. For example, in the plate where a normal detects the yellow-green number "5" in the orange background, the color defective, not being able to distinguish yellow-green from orange, detects instead the pale pink "2" in the orange background. Reversible-number plates are included in the set primarily to detect malingerers - an examinee must respond

with either a "5" or a "2". This test requires 28 seconds to administer. Time for test administration is mentioned because it is always desirable that a test for service use be rapid.

The second set - The Dvorine Set - "meets the requirements of the military services" as is stated by the Armed Services Medical Materiel Coordination Committee. This Dvorine set contains no reversible-number plates. It does, however, contain two plates which are designed to distinguish protans from deutans - the "95" and the "26". In these plates, the double-digit number is composed of gray circles, with the first digit appearing in a pink background and the second digit appearing in a red-purple background. Protans should see only the second digit because gray and pink look alike to them, whereas deutans should see only the first digit because gray and red-purple look alike to them.

Also, the Dvorine set states that an error score of 5-11 indicates moderate color vision deficiency and an error score of 12-14 indicates severe color vision deficiency. In addition to use of the Dvorine test by the Army, Navy, and Air Force, it is stated that the Administrator of the Civil Aeronautics Administration considers it acceptable for use in testing color vision in the medical certification of airmen when daylight or approximate daylight illumination is used. For purposes of medical certification, failure to read correctly 5 or more of the 14 test plates indicates defective red-green color vision. This test requires 1 minute and 10 seconds to administer.

Lantern tests, which are designed to salvage some of the applicants who fail plates, present specially-selected colored lights which are correctly identified by the milder color defectives and incorrectly named by the more severe color defectives. The Farnsworth Lantern (referred to as the FaLant test) is used by the U.S. Navy as the final validating color vision test, may be used by the Army for qualification of pilots, and, if available, is authorized for use by the F.A.A. Examining Physicians. In addition, the Coast Guard and Merchant Marine Academies utilize it for final determination for acceptance. It consists of red, green, and white lights which are presented two at a time in nine different color combinations. A 50% neutral filter reduces the brightness of one of the lights in each of the nine pairs. The test is administered at an eight-foot distance and the lights are exposed in random order for about two seconds per exposure. It does not require a dark room because the aperture plate is recessed 4-1/4 inches from the face of the lantern and hence normal room illumination does not affect the test results. A pass score consists of no errors on the first run of nine lights or an average of one wrong or less on the next two runs. It requires 18 or 54 seconds to administer.

The other lantern test used by the U.S. Armed Forces is the Color Threshold Tester. It is authorized for qualification of Air Force pilots and astronauts. A score of 50 or better is required for Flying Class II or III; a score of 34 or better is required for

entrance to the Air Force Academy. It consists of eight colored lights - two reds, two greens, an orange, yellow, blue, and white - presented at eight different intensities. All eight colors are presented in order at the lowest intensity level first, then at the next highest intensity level in reverse order; this procedure is continued at each of the eight intensity levels, alternating the order of presentation. The examinee simply names each color and a perfect score is 64. The test is administered at a ten-foot distance and the sixty-four lights are exposed for about 5 seconds per exposure. A dark room is required and it takes 5 minutes and 20 seconds to administer the test.

The Bausch & Lomb Ortho-Rater Color Vision Test Slide No. 71-21-21 is an Army test and is used for qualification of commissioned officers and for entrance to the U.S. Military Academy; in addition, it is in use at the Armed Forces Entrance and Examining Stations. It is a slide for binocular distance vision which consists of nine colored circles - three identical reds, three identical greens, and three identical yellows. The examinee is asked to identify the color of the circles. Identification of one circle each in red and green color is considered a passing score. It takes 15 seconds to administer.

The lantern used by the Royal Canadian Armed Forces consists of 1 red, 2 green, and 3 white lights which are presented singly and in pairs of various combinations. The test is administered at a twenty-foot distance and the lights are exposed in consecu-

tive order for about two seconds per exposure. A darkened room is required. A pass score consists of no errors on the first test (11 single lights and 11 pairs of lights) or one error on the first test and none on repeat test. It requires 44 seconds or 1 minute and 28 seconds to administer.

COMPARISON STANDARD - THE NSMRL BATTERY OF COLOR VISION TESTS

All the subjects examined on these six color vision tests were classified as to type (protan* or deutan**) and degree (mild, moderate, severe, or dichromatic) by the NSMRL Battery of color vision tests. The results obtained on the six tests were compared with the results obtained on the NSMRL Battery. Table I presents this battery. To determine the type of defect (protan or deutan), an anomaloscope is used for the mild and the moderate and the D-15 Test is used for the severe and dichromatic. These four tests will be explained very briefly for this has been done in several previous papers and NSMRL reports.^{1,2,3}

The first test in our battery is a set of improved American Optical Company (A.O.) plates developed at NSMRL by CDR Dean Farnsworth.⁴ Some of the improvements to the A.O. plates are as follows: (1) Changes were

*Protans are commonly called "red-defective"; their major confusion is between certain reds, grays, and bluish-greens and they have a reduced sensitivity in the red end of the visible spectrum.

**Deutans are commonly called "green-defective"; their major confusion is between certain greens, grays, and purplish reds.

made in the shape of the numbers so that normals would not miscall them; block numbers replaced the Germanic numbers. (2) A uniform background pattern was designed and the white rivers between numbers and background circles were eliminated; these changes removed two aids to memorization of plates by color defectives. (3) Some colorimetric specifications were changed so that they plotted more exactly within the confusion zones of color defectives. Three copies of this set were produced. Although detailed specifications are available, this set has never been mass-produced. Colorimetric specifications for these NSMRL improved A.O. plates are found in Appendix A.

The second test, the FaLant was just described; further information is available in several reports.^{1,2} Colorimetric specifications for the FaLant filters appear in Appendix B.

The Dichotomous-15 Test⁵ consists of a series of colored buttons presented in random order for the subject to arrange in a consecutive color order. Normals, mild and moderate color defectives arrange these buttons as depicted in Fig. 2. This figure is Farnsworth's projective transformation of the C.I.E. Diagram;⁶ the chromaticity coordinates of each button are plotted thereon. The Munsell hue designation of each button is also listed.

Table I. Degree of Color Vision Defect as Determined by Performance on NSMRL Test Battery

Classification	NSMRL TEST BATTERY			
	Pseudo-iso-chromatic Plates	FaLant	D-15	H-16
Normal Trichromat	Pass	Pass	Pass	Pass
Mild Anomalous Trichromat	Fail	Pass	Pass	Pass
Moderate Anomalous Trichromat	Fail	Fail	Pass	Pass
Severe Anomalous Trichromat	Fail	Fail	Fail	Pass
Dichromat	Fail	Fail	Fail	Fail

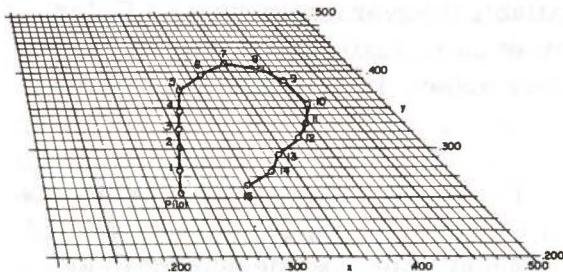


Fig. 2. Arrangement of D-15 buttons by normals and by mild and moderate color defectives.

Figure 3 shows how a severe or dichromatic protan would arrange the buttons; next to the pilot button, he places #15 rather than #1 because Munsell hue 10.0 B and 5.0 P are in his confusion zone and look alike to him, whereas 10.0 B and 5.0 B are in his color differentiation zone and look different to him, and similarly back and forth across the diagram. In this and the following diagrams, the solid lines indicate the confusion lines.

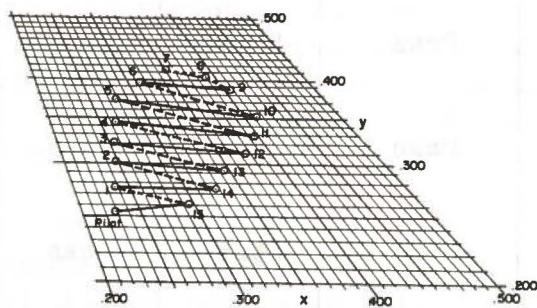


Fig. 3. Arrangement of D-15 buttons by severe and dichromatic protans.

Figure 4 shows how a severe or dichromatic deutan would perform on this test; to him, the 10.0 BG and the 5.0 P look alike, etc. The colorimetric specifications for the D-15 Test appear in Appendix C.

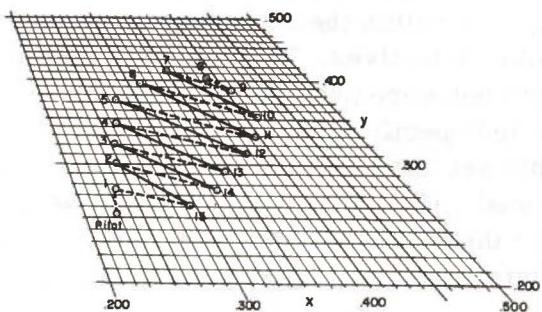


Fig. 4. Arrangement of D-15 buttons by severe and dichromatic deutans.

The last test in the NSMRL Battery is the H-16. It has never been mass-produced; colorimetric specifications for it appear in Appendix D. Like the D-15, it consists of a series of colored buttons to be arranged in a consecutive color order. The chromaticities of these pigments lie farther out on the C.I.E. Diagram than those of the D-15 Test, and hence the test is easier for color defectives to pass. Normals, mild, moderate, and severe color defectives arrange these buttons as depicted in Figure 5. Again, this figure is Farnsworth's projective transformation of the C.I.E. Diagram, on which the chromaticity coordinates of each button are plotted; Munsell hue designations of the buttons are also listed. Figure 6 shows how a dichro-

matic protan would arrange the buttons and Fig. 7 shows how a dichromatic deutan performs on this test. Good agreement has been found between failure on this NSMRL H-16 test, which is rapid and easy to administer, and two anomaloscope tests for dichromacy. In classical usage of the anomaloscope, a color defective is defined as a dichromat if he matches the entire range of various mixtures of red and green filtered light appearing in one half of the test field to the yellow light which appears in the other half of the test field. The examinee is able to adjust the brightness of the latter field. The other anomaloscope test is an NSMRL innovation in which (1) the yellow filter is removed and replaced with the green filter, and (2) a blue filter is inserted so that varying amounts of it may be mixed with the red filter for the purpose of desaturating the red. Dichromats find a match on this latter anomaloscope by adjustment of the brightness of the green field and the saturation of the red field and will call this green-to-red match a yellow-to-yellow match.

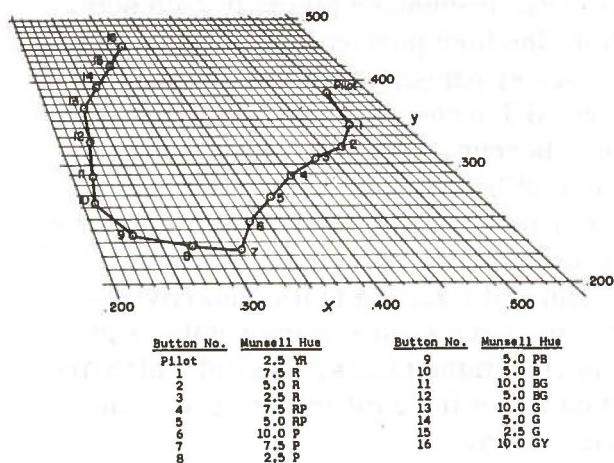


Fig. 5. Arrangement of H-16 buttons by normals and by mild, moderate, and severe color defectives.

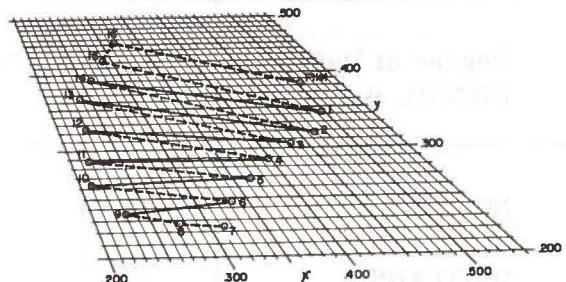


Fig. 6. Arrangement of H-16 buttons by dichromatic protans.

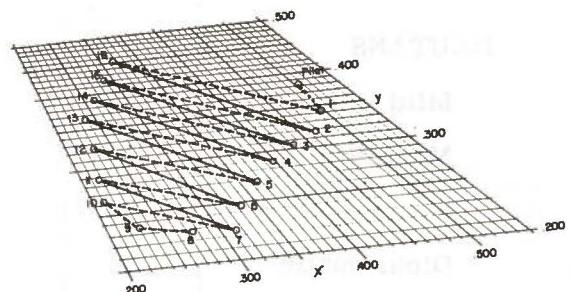


Fig. 7. Arrangement of H-16 buttons by dichromatic deutans.

RESULTS

1. The Armed Forces Color Vision Test by A.O. Co.

This test was administered to 48 normals, 53 protans, and 203 deutans. The average error score, out of a possible 14, is shown in Table II; also reported are the average error scores obtained by the same individuals on the NSMRL improved version of the test. Note that the improved version functions better in the sense that higher

Table II. Average Error Score on Armed Forces A.O. Set and NSMRL Improved A.O. Set

Degree of Defect (NSMRL Battery)	N	Armed Forces Set	NSMRL Improved Set
NORMALS	48	1.6	0.7
PROTANS			
Mild	11	9.5	12.2
Moderate	13	11.3	13.6
Severe	20	12.2	13.9
Dichromatic	9	12.8	14.0
DEUTANS			
Mild	121	7.3	9.7
Moderate	20	10.4	12.9
Severe	30	11.0	13.5
Dichromatic	32	11.0	13.4

error scores are made by all categories of color defectives and lower error scores occur for normals. Also note that in both sets the average error score increases as the degree of defect increases and that protans in each degree-of-defect category have a higher average error score than deutans.

As mentioned previously, the Armed Forces Color Vision Test has six reversible-number plates to which normals should respond with one number and color defectives with another. The NSMRL improved version also contains six reversible-number plates. Figure 8 shows, for protans and deutans, the

percentages of normal responses to the reversible-number plates in both sets. Note the high percentage of normal responses, especially by deutans, in the Armed Forces set. This is a poor feature because the person administering the test becomes confused when the color defective gives the same response to these plates as he, the examiner, would and fails the test primarily because he does not see the numbers in the remaining plates, most of which are faint and a little difficult to see even for normals.

In summary, the Armed Forces Color Vision Test does evoke a higher

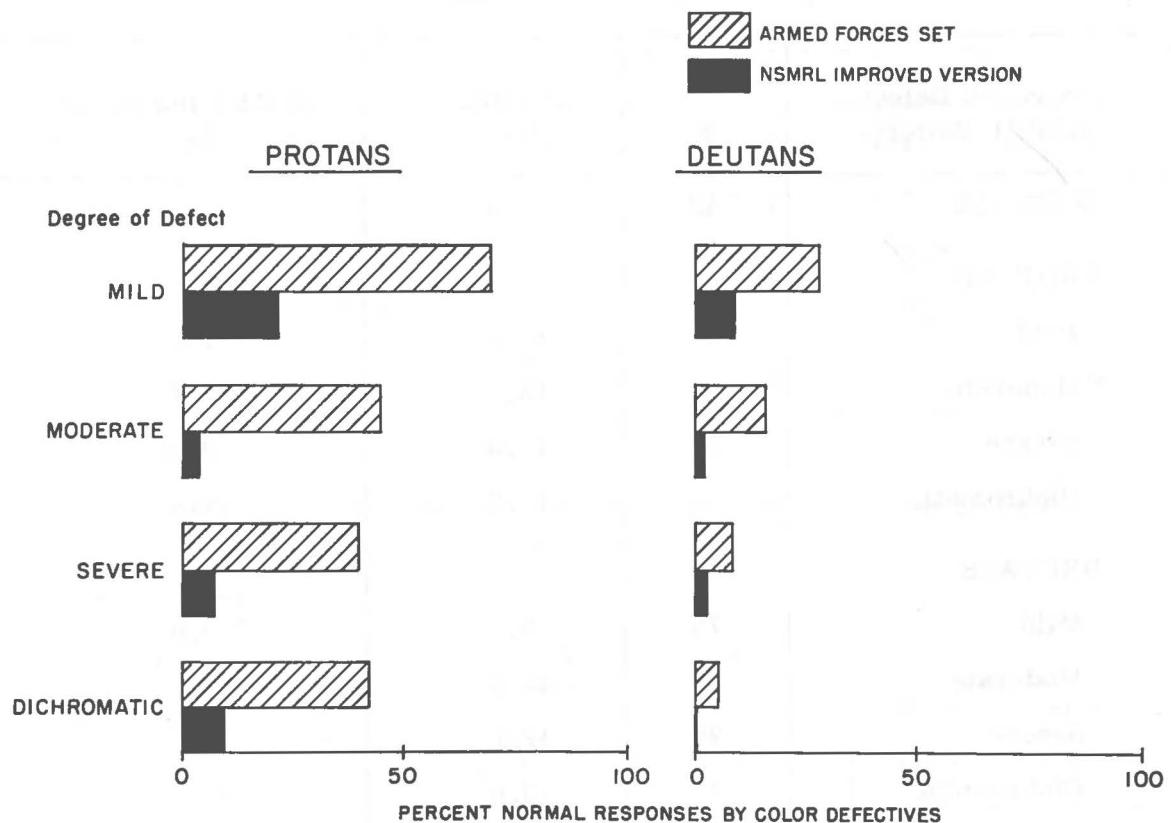


Fig. 8. Normal responses to reversible-number plates of the Armed Forces Set and the NSMRL Improved Version.

error score as the degree of defect increases in severity, and it correctly identifies 94% of normals as normal and 95% of color defectives as color defective. However, its reversible-number plates incorrectly evoke normal responses from color defectives 4% of the time.

2. The Dvorine Pseudo-Isochromatic Plates

This test was administered to 42 normals, 42 protans, and 157 deutans. The average error score on this set

compared with NSMRL's improved set is shown in Table III. Again, for both sets, the average error score increases as the degree of defect increases and the protans in each degree-of-defect category have a higher average error score than deutans. In six of the eight color defective categories, the NSMRL improved set evokes slightly more errors than the Dvorine set, with two of the eight categories being equal. Although the Dvorine average error scores are not quite as high as the NSMRL improved set, they are considerably higher than those of the Armed Forces Color Vision Test.

Table III. Average Error Score on Dvorine Plates and NSMRL Improved A.O. Set

Degree of Defect (NSMRL Battery)	N	Dvorine Set	NSMRL Improved Set
NORMALS	42	0.6	0.4
PROTANS			
Mild	10	10.8	11.3
Moderate	12	12.8	13.7
Severe	14	13.9	13.9
Dichromatic	6	14.0	14.0
DEUTANS			
Mild	73	9.5	9.9
Moderate	26	12.6	12.7
Severe	25	12.8	13.1
Dichromatic	33	13.0	13.3

As mentioned previously, the Dvorine set contains two plates which are designed to indicate type of defect. Table IV gives the results for each of these two plates, compared with the NSMRL battery. The agreement is poor, largely because the Dvorine plates render no classification much of the time (that is, the color defectives see both digits or no digit in the double-digit number). Mild color defectives tend to see all four digits in the two plates (34% of them did so) and the more severe color defectives tend to see none of the digits (44% of the dichromats did so). A more serious fault than no classification is an incorrect classification and it is seen in Table IV that this does not occur very often.

The Dvorine set also claims to indicate degree of defect based on total error score. An error score of 5-11 is supposed to indicate moderate deficiency and 12-14 severe deficiency. Table V shows how the test performs in this respect as compared with the NSMRL classification. It appears that the Dvorine degree-of-defect classification is too stringent. For example, classified by Dvorine as severe color defectives are 60% of NSMRL's mild protans, 83% of NSMRL's moderate protans, and 81% of NSMRL's moderate deutans.

In summary, the Dvorine test is a better test than the Armed Forces Color

Table IV. Comparison between Dvorine and NSMRL Type-of-Defect Classification (Dvorine Plates # 95 and # 26)

Plate #	Agrees with NSMRL Classification		Renders No Classification		Disagrees with NSMRL Classification	
95	PROTS 24%	DEUTS 33%	PROTS 76%	DEUTS 62%	PROTS 0%	DEUTS 5%
26	9	52	79	45	12	3

Table V. Comparison between Dvorine and NSMRL Degree-of-Defect Classification

Degree of Defect (NSMRL Battery)	Dvorine Classification					
	Normal (0-4X)		Moderate (5-11X)		Severe (12-14X)	
	PROT	DEUT	PROT	DEUT	PROT	DEUT
Mild	0%	8%	40%	64%	60%	28%
Moderate			17	19	83	81
Severe			0	12	100	88
Dichromatic			0	12	100	88

Vision Test in that (1) more of the plates are failed by color defectives and fewer are failed by normals, and (2) it correctly identifies 100% of normals as normal and 98% of color defectives as color defective. However, its classification of color defectives as to type is not effective and its classification of color defectives as to degree is too stringent.

3. The Bausch & Lomb Color Slide 71-21-21

This slide was administered to 34 normals, 161 protans, and 215 deutans. The data were analyzed using the official scoring method and two other criteria. The official scoring method is "1 red and 1 green correctly identified results

in a pass score." A second, more stringent method of "all 3 reds and 3 greens correctly identified results in a pass score" and finally, the most stringent method of "all reds, greens, and yellows correctly identified results in a pass score" were used to see if a more stringent scoring method would fail more color defectives.

The results of these three scoring methods are seen in Figures 9 and 10 for protans and deutans, respectively. Not indicated in these figures are the data for normals: Method 1 passes 100% of the normals, Method 2, 97%, and Method 3, 94%. With the official scoring method, most color defective individuals pass the test; in fact, it fails only 12% of a color defective population. The more stringent scoring methods result in some improvement but the percentage passing, with even the most stringent method, is still high - 72% of the color defective population pass by this criterion.

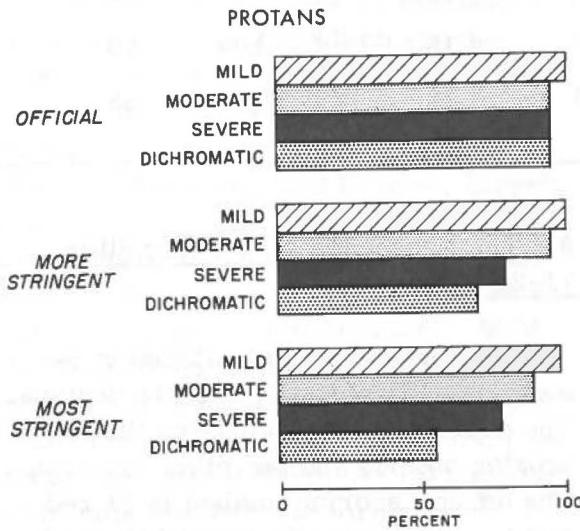


Fig. 9. Percentage of protans passing B & L Color Slide by three scoring methods.

4. The Farnsworth Lantern

Detailed data on the performance of the FaLant, compared to the degree of color vision defect, are found in previous reports.^{1,2} These data show that the median error score on the FaLant increases as the degree of defect increases and that the protans consistently make more errors, on the average, than deutans. The characteristic errors made by color defectives in naming the colored pairs of lights in the FaLant also are found in the previous reports.

5. The Color Threshold Tester (CTT)

This lantern was administered to 20 normals, 94 protans, and 130 deutans. Figure 11 shows the means and ranges of scores, out of a possible 64, obtained by normals and the various degrees of protans and deutans. The average CTT score is related to the degree of defect but there is considerable spread around the average.

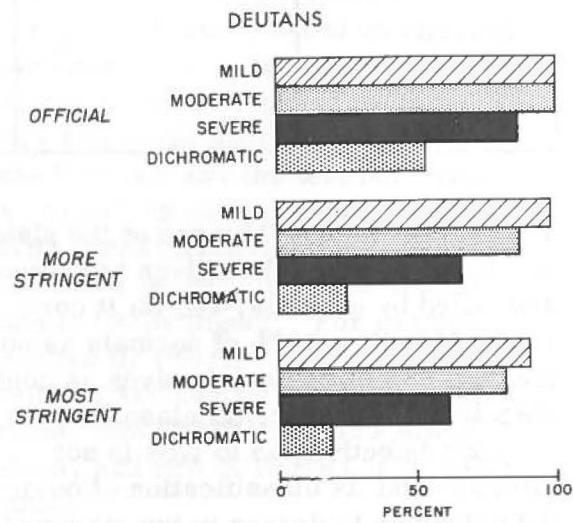


Fig. 10. Percentage of deutans passing B & L Color Slide by three scoring methods.

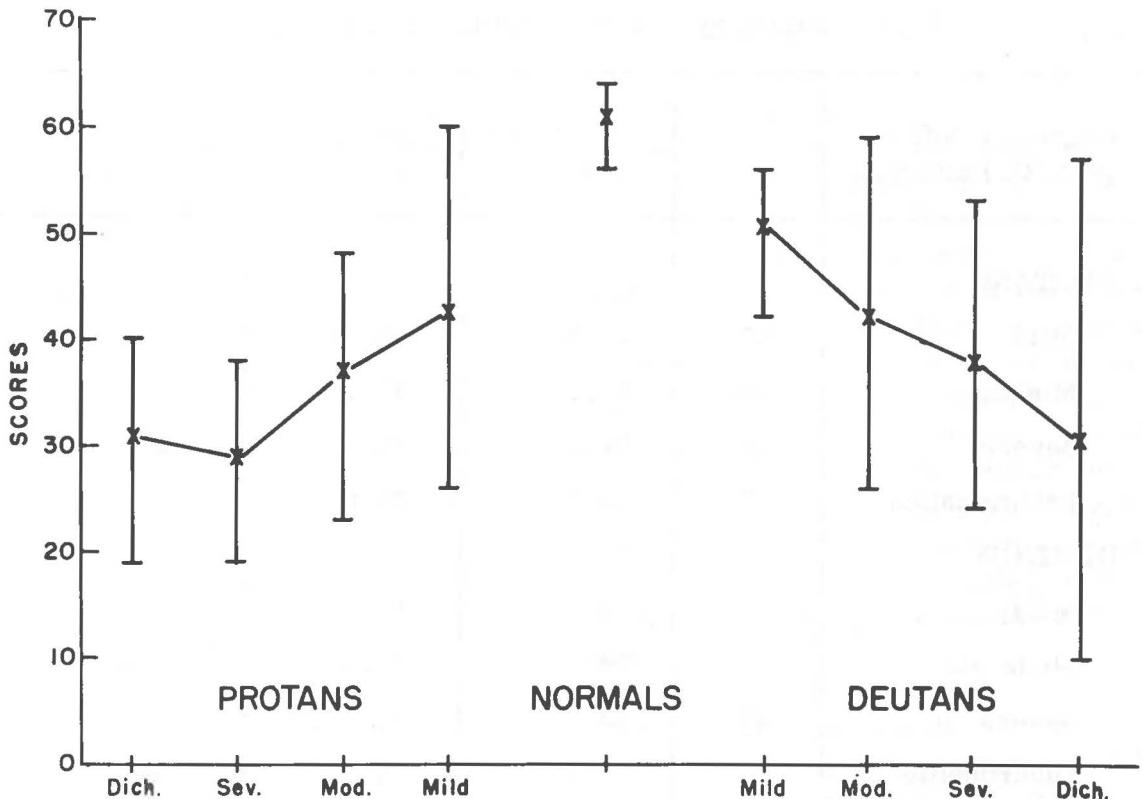


Fig. 11. Means and ranges of Color Threshold Tester scores.

Table VI compares the proportion of men falling into categories, specified by the Air Force for various grades of defective color vision, with the NSMRL classification. The Air Force Deficient Color Perception Grade 1 is 50 or better, Grade 2 is 49-35, and Grade 3 is 34 or less. Grade 3 is entitled "complete red-green deficiency" in the AF Manual. While there is general agreement, that is, the greater the defect the lower the CTT score, there are some discrepancies. For example, of the 27 men rated as mild protan by the NSMRL Battery, 18% were rated as Deficient Grade 1, 63% as Grade 2, and 18% as complete red-green deficient. Similar lack of differentiation by the CTT was

apparent in some cases in Fig. 11; the severe and dichromatic protans, for example, obtain the same average score.

Figure 12 shows for both protans and deutans the mean score obtained by the various degrees of color defectives for each of the individual colored lights in the CTT. A score of 8 means that the individual colored light was called correctly at all 8 intensity levels. No. 3 Green (bluish-green) and No. 7 White are the most difficult and No. 5 is the easiest.

Characteristic errors made by color defectives are the failure to see the blue light at the dimmest intensities;

Table VI. Percentage of Men Categorized According to Air Force Grading System and NSMRL Classification

Degree of Defect (NSMRL Battery)	N	Color Threshold Test Scores		
		Grade 3	Grade 2	Grade 1
PROTANS				
Mild	27	18.5%	63 %	18.5%
Moderate	35	37.1	62.9	0
Severe	19	84.2	15.8	0
Dichromatic	13	69.2	30.8	0
DEUTANS				
Mild	25	0	48	52
Moderate	42	19	64.3	16.7
Severe	31	32.3	64.5	3.2
Dichromatic	32	78.1	18.8	3.1

calling the white at low levels "green", the green at high levels "white", and bright red "orange"; and failure of protans to detect the dimmest reds. Also, the examinee's responses are greatly influenced by the color of the preceding light - for example, white is called "green" when it follows the red light and called "white", "orange" or "yellow" when, moving in reverse order of presentation, it follows the green light.

Figure 13 provides a direct comparison between the CTT and the FaLant by giving the errors made by the same examinees on each lantern. For this analysis, the error scores for each lantern have been converted to percentages out of the total possible errors.

While there is general agreement that individuals with greater defect make more errors, the FaLant is superior in differentiating among categories.

6. The C-11 Colour Perception Lantern

The final test results are from the Colour Perception Lantern used by the Canadian Armed Forces. This test, only recently obtained for evaluation, was administered to only 10 normals, 41 protans, and 53 deutans. It passes only 6% of a color defective population.

Figure 14 shows the means and ranges of error scores, out of a possible eleven, obtained by normals and the various degrees of protans and deutans

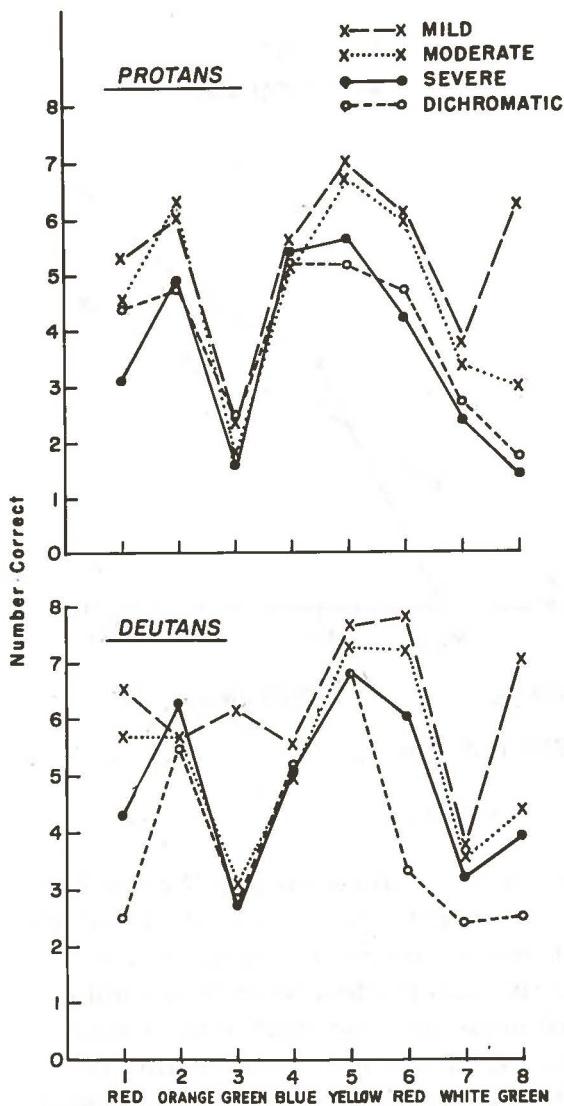


Fig. 12. Mean scores obtained by protans and deutans for the individual colored lights in the Color Threshold Tester.

for the single light test and the pairs of lights test. The data show that this Lantern does have internal validity in that there is a consistent increase in average score with increase in degree of defect, although, again there is considerable spread.

The percentages of errors obtained by the various examinees for each of the colored lights in the Colour Perception Lantern are shown for the single light test and pairs of lights test respectively, in Figures 15 and 16. There are few lights or pairs of lights which are consistently the most difficult or the easiest for color defectives. Differentiation of degree of defect is better for the double light test, for all colors, than for the single. The characteristic errors made by color defectives in this test are confusion of green and white colored lights, white light called the complement of the color with which it is presented, and the inability of the protan to see the red light.

Figure 17 shows the direct comparison of error scores by the same examinees on the C-11 Lantern and the FaLant. Once again, differentiation of defect is better for the double light test and almost as good as that of the FaLant.

DISCUSSION

1. Plate Tests

A valid set of pseudo-isochromatic plates is still considered advisable for use by the military services in screening large numbers of men for color deficiency. They are inexpensive to purchase, easy to administer and score, give unequivocal results, do not require dark alleys or extensive testing facilities, and have a long life if properly handled.

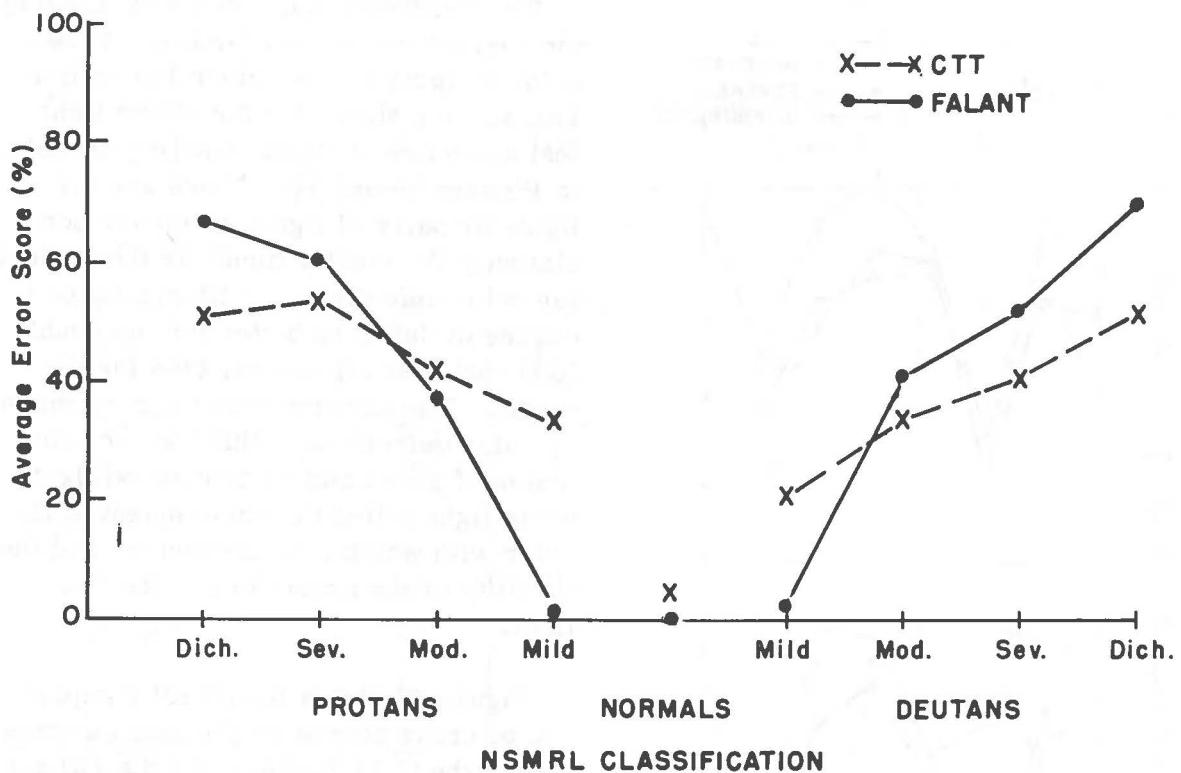


Fig. 13. Comparison of errors on CTT and FaLant.

A few points should be made about plate tests, in general, however. (1) Not all color defectives fail all the plates* and hence the entire selection must be administered; many of the Navy color defectives report that they "passed" plates when only one or two plates were shown. (2) The plates must be administered under Illuminant C (simulated daylight); the hues of the number and its background were selected specifically since they are indistinguishable to color defectives in this light. They may look quite distinct from one another to color defectives in

other types of illumination. As has been well documented in the literature for the past twenty-five years, deutans frequently pass the test when it is administered under incandescent light or sunlight. Even so, half of the testing facilities surveyed a few years ago lacked the daylight lamp. (3) A small percentage of normals will fail a set of plates, but such failures can readily be differentiated from color defective failures. They are caused by a tendency to complete numbers ("3" to "8", "5" to "6", etc.), by poor hue discrimination, by visual defects other than color, etc. (4) Plates are memorizable and, to offset this, they must be administered rapidly and in random order. (5) To offset fading and deterioration of the pigments, the book of plates should be kept closed

*Those interested in the merit of the individual plates in the three sets evaluated in this paper are referred to Appendix E.

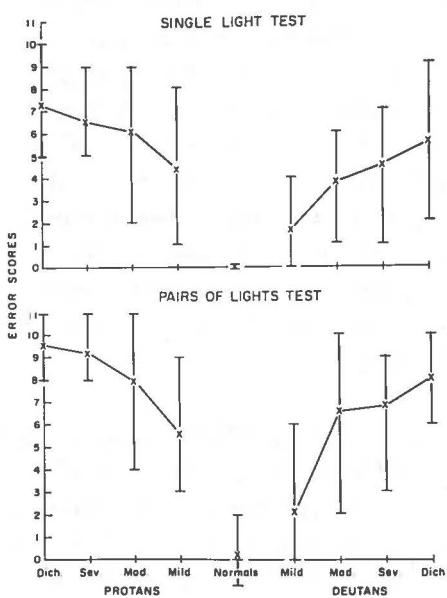


Fig. 14. Means and ranges of Colour Perception Lantern error scores for single light test and pairs of lights test.

when not in use and the plates should never be fingered by examinee or examiner.

Of the two plate tests used by the military services, the Dvorine is superior to the Armed Forces set. It is suggested, however, that the additional information given the examiner relative to indications of type of defect and degree of defect be eliminated from the Dvorine sets produced for use by the military services. The Armed Forces set could be considerably improved by small changes in the colorimetric specifications of the pigments and by changes in the shape of the numbers, as has been done in the NSMRL version. For example, the reversible-number "3" in the Armed Forces set was failed by 69.8% of the color defectives,

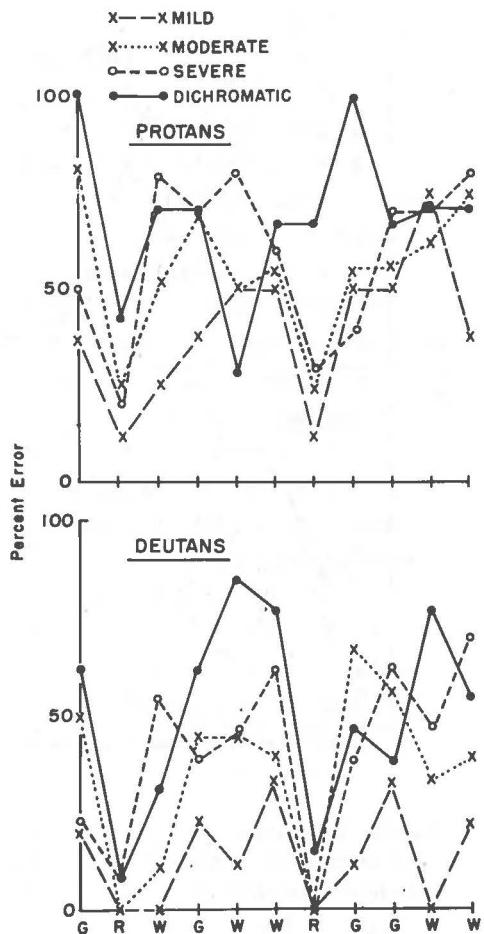


Fig. 15. Percentages of errors obtained by protans and deutans for each of the colored lights in the Colour Perception Lantern single light test.

whereas the reversible-number "3" in the NSMRL version (same shape, but different color) was failed by 94.8% of the color defectives. Similarly, the "47" in the Armed Forces set was failed by 45.8% of the normals, whereas the "47" in the NSMRL version (same color, but different shape) was failed by 3.3% of the normals.

2. The Bausch & Lomb Color Slide 71-21-21

The data show that this test is the least valid color vision test in use by the U. S. military service. It is

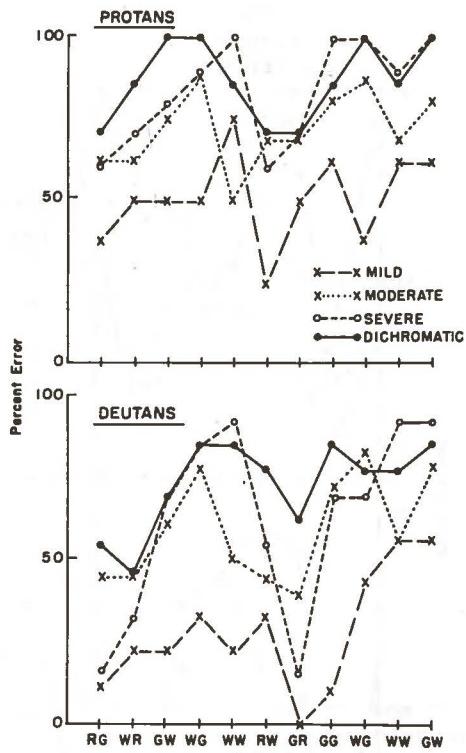


Fig. 16. Percentages of errors obtained by protans and deutans for each of the colored lights in the Colour Perception Lantern pairs of lights test.

commonly found in Armed Forces Entrance and Examining Stations, where it is employed as the referral test for those who fail plates. As such, it provides misleading information on those signing up for tours of duty in the Armed Forces by passing 88% of the color defectives. For this reason, the attempt was made to improve the test's performance by the use of more stringent scoring methods, but the improvement found was slight.

There are several other unfortunate features about this test. (1) The color defectives who failed the test by the official scoring method all did so by failing to call any of the reds correctly. Of these incorrect responses to red, 90% were orange responses. Such a failure is vulnerable to the attack of those who claim the examinee failed the test because of slight errors

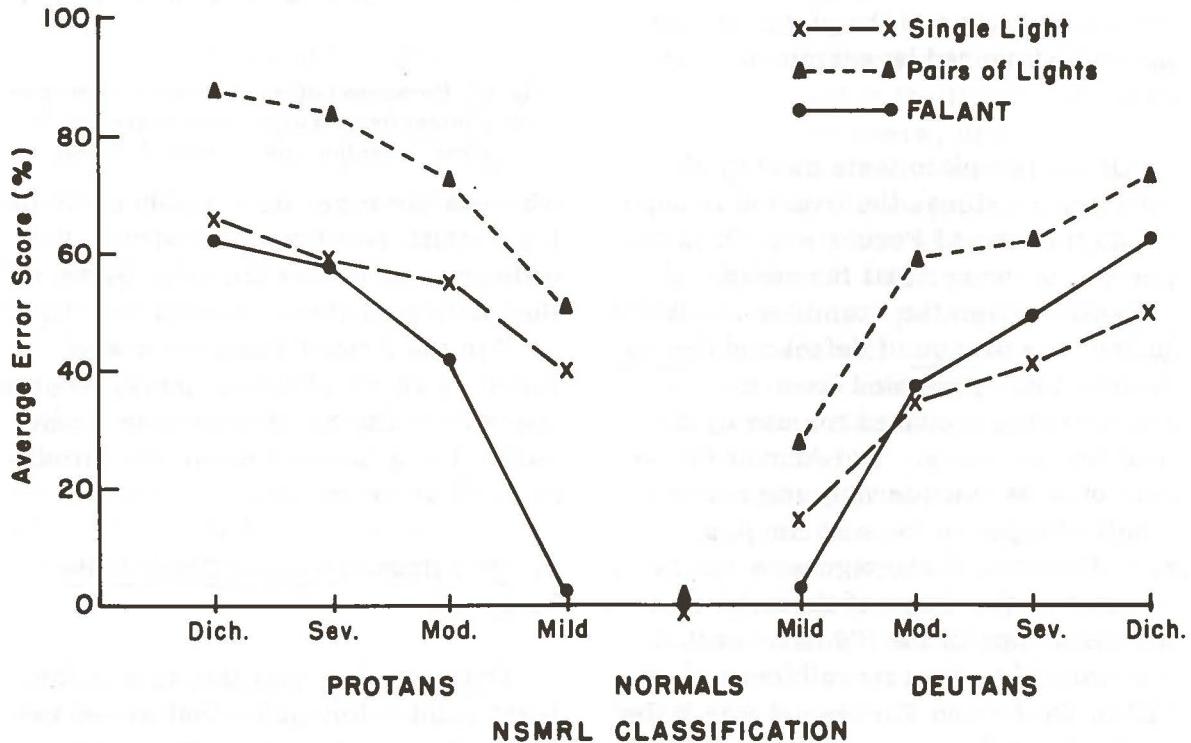


Fig. 17. Comparison of errors on Colour Perception Lantern and FaLant.

in color naming instead of defective color perception; even a few normals will call one of the reds "orange". (2) Although Army Regulation 601-270 states that the examinees are not to be advised in advance as to the colors used in the test, the fact that the three colors in the test are red, green, and yellow inevitably becomes general knowledge. This knowledge enables those few color defectives who might otherwise fail the test to pass it because they could call "red" those three colors that look orange to them or that look different than the three greens and three yellows. (3) The slide is easily memorizable because the colors cannot be exposed and judged individually; the colors are numbered and are permanently arranged in one set way. Finally, (4) the test is especially incongruous for protans; 100% of the mild protans pass it and 95% of the moderate, severe, and dichromatic protans pass it. The typical error - "red" called "orange" - does not occur; to a protan, with his reduced luminosity function, the red appears too dark to be called "orange".

Recently, the Federal Aeronautics Association has authorized use of the other color vision test slide in the Bausch & Lomb Ortho-Rater; namely, the slide containing the four pseudo-isochromatic plates. This slide is also easily memorizable because the plates cannot be exposed and judged individually. Although this slide does fail 99.3% of color defectives who have not memorized the four numbers, it also fails 56% of the normals. For the interested reader, data on this slide appear in Appendix F.

3. Lantern Tests

The use of a lantern test is still considered advisable for salvaging the mild color defectives and those few normals who might fail a plate test. In other words, the 10% of the male military population that fails plates should be tested with a lantern. Unpublished data at NSMRL indicate that those color defectives who fail plates but pass the FaLant are as accurate as normals in judging typical colors used by the services for coding, signaling, and communication. Since the FaLant became the final, validating test for color vision in the U. S. Navy in 1954, thirty of every hundred color defectives have been salvaged for training as line officers, submariners, electronic technicians, pilots, etc.

Of the three lanterns evaluated in this paper, the Colour Perception Lantern, when administered in accordance with the instructions, has too low a salvage value (six in a hundred color defectives) to be worth the time, effort, and expense of referring men who fail plates for testing on the lantern. However, it appears that, although the test manual and the instructions imprinted on the cover state a 20-foot distance, the lantern was validated at and often used at a 15-foot distance. Recently, data collected with the test administered at both distances at NSMRL indicate that some mildly pass at the 15-foot distance but moderates, severes, and dichromats do not. Further data on the effect of testing distance on the performance of the Colour Perception Lantern would appear advisable. Our

data also indicate the superiority of the pairs of lights test over the single light test.

While all lanterns in this study perform similarly in a general way, the FaLant differentiates among degree of defect more effectively, salvages individuals with mild defects, and has the additional advantages of a brief testing time and not requiring the use of a dark room.

CONCLUSION

The results presented in this paper show that men with different degrees of color vision defect are being accepted by different color vision tests currently in use by the various Departments and Agencies within the government. To the extent that similar specialties exist within these various organizations, a man with a mild degree of defect can maximize his chances of being accepted for training by selecting the Department or Agency with the most lenient test. For example, if a color defective is mild, he is qualified to fly Navy planes. He is qualified to fly Army planes if the examining station uses the FaLant Test and, if it uses a Plate Test (use of either a Plate Test or the FaLant is acceptable), he has a 7% chance of being qualified if the Armed Forces A.O. Set is used and a 4% chance if the Dvorine Set is used. He has a 18.5% chance to be qualified to fly Air Force planes and NASA space vehicles if he is protan and 52% if he is deutan. To be licensed by the F.A.A., he is qualified if the FaLant test is used and, if the Dvorine Plate Test is used (again, either test is acceptable), he has a 0% chance if he is protan and an 8% chance if he is deutan.

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**Appendix A. Colorimetric Specifications for Colors Used
in NSMRL Improved Version of A.O. Plates**

Plate #	Munsell Designation	
	Hue	Value/Chroma
Reversible-numbers 8, 6, and 29	10.0 R	7.6/5
	3.0 YR	6.7/8
	6.0 YR	7.8/7
	7.5 YR	6.6/3
	8.0 YR	6.2/7
	10.0 Y	7.8/6
	4.5 GY	6.0/6
	4.5 GY	7.1/5.5
	7.5 GY	7.5/4
	2.5 G	6.0/4.5
27, 42, and 56	8.5 R	6.2/10
	1.5 YR	6.8/9
	5.0 YR	7.2/7.5
	6.5 YR	8.0/8
	4.0 Y	6.2/5
	7.0 Y	7.8/6.5
	7.5 Y	5.2/4
	8.0 Y	6.0/5
25, 68, and 97	7.0 R	4.8/6
	1.0 YR	7.0/6
	6.0 YR	7.8/5
	2.5 Y	7.5/3
	5.0 Y	6.8/3.5
	5.0 GY	5.0/2
Reversible-numbers 5, 3, and 74	10.0 R	7.2/7.5
	2.3 YR	6.2/10
	7.5 YR	7.4/7
	10.0 YR	8.2/3.5
	10.0 YR	8.5/8
	8.0 Y	8.4/6
	2.5 GY	7.6/4.7
	5.0 GY	6.2/4.7
	7.5 GY	8.0/3
	4.0 G	6.5/4.7

Appendix A. Colorimetric Specifications for Colors Used
in NSMRL Improved Version of A.O. Plates (cont)

Plate #	Hue	Munsell Designation Value/Chroma
47 and 98	10.0 R	5.8/5
	5.0 YR	4.8/4
	5.0 YR	6.8/6
	5.0 YR	7.1/6.5
	7.5 YR	5.0/4.3
	8.0 YR	6.5/5
	10.0 YR	7.8/6
	2.5 Y	7.3/4

Appendix B. Colorimetric Specifications for FaLant Filters

1. The red filter shall have $6 \pm 0.5\%$ transmittance and the green and the neutral (white) filters shall have $5 \pm 0.5\%$ transmittance. The C.I.E. trichromatic coefficients, calculated for Illuminant A, shall fall within the following boundaries:

Red		Green		Neutral	
x	y	x	y	x	y
.620	.320	.200	.740	.430	.410
.580	.300	.160	.680	.460	.440
.600	.280	.210	.650	.490	.420
.660	.280	.250	.710	.460	.390

2. A neutral dimming filter, with a $50 \pm 5.0\%$ transmittance and the same trichromatic coefficients as listed above for the 5% neutral filter, shall be inserted with the following filters in each pair:

- GR - with the red
- WG - with the green
- GW - with the white
- GG - with the first green
- RG - with the red
- WR - with the white
- WW - with the second white
- RW - with the red
- RR - with the first red

3. Behind the aperture plate there shall be a clear glass, etched on both sides, with a transmittance before etching of approximately 92% and after etching of 68-76% and a neutral glass, etched on both sides, with a transmittance before etching of $30 \pm 3\%$ and after etching of 20-25%. The neutral glass shall have the same trichromatic coefficients as listed above for the 5% neutral filter. (These aperture plate glasses diffuse the light source and reduce the brightness of the stimuli.)

4. The neutral filter shall meet the Judd Daylight Duplication Index (shortened form), as follows: the 5% neutral shall be less than 8, the 50% neutral shall be less than 3, and the neutral aperture plate glass shall be less than 4. (This Judd Daylight Duplication Index is a standard military specification for insuring the neutrality of sunglasses, goggles, and visors.)

5. The light source is an incandescent clear General Electric Airport Marker Lamp, 40 watt, 115 volt, T-8 bulb, CC-2V filament (Code 40T8/3).

Appendix C. Dichotomous-15 Test Specifications

Button No.	Trichromatic Coordinates		Munsell Designation	
	x	y		
Pilot	.228	.254	10.0 B	5/6
1	.235	.277	5.0 B	5/4
2	.247	.301	10.0 BG	5/4
3	.254	.322	5.0 BG	5/4
4	.264	.346	10.0 G	5/4
5	.278	.375	5.0 G	5/4
6	.312	.397	10.0 GY	5/4
7	.350	.412	5.0 GY	5/4
8	.390	.406	5.0 Y	5/4
9	.407	.388	10.0 YR	5/4
10	.412	.351	2.5 YR	5/4
11	.397	.330	7.5 R	5/4
12	.376	.312	2.5 R	5/4
13	.343	.293	5.0 RP	5/4
14	.326	.276	10.0 P	5/4
15	.295	.261	5.0 P	5/4

Appendix D. Colorimetric Specifications for H-16 Test

Button No.	Trichromatic Coordinates		Munsell Designation		Munsell Production No.
	x	y	Hue	Value/Chroma	
Pilot	.504	.383	2.5 YR	5/10	1551
1	.496	.341	7.5 R	5/10	1536A
2	.469	.318	5.0 R	5/8	738
3	.431	.304	2.5 R	5/8	1585
4	.398	.288	7.5 RP	5/8(approx.)	4032
5	.365	.268	5.0 RP	5/8(approx.)	4034
6	.334	.246	10.0 P	5/8	698
7	.313	.225	7.5 P	5/8	1833
8	.275	.228	2.5 P	5/6	1935
9	.230	.236	5.0 PB	5/8	1302
10	.211	.263	5.0 B	5/6	1276
11	.217	.289	10.0 BG	5/6	658
12	.230	.327	5.0 BG	5/6	1115
13	.238	.364	10.0 G	5/6	644
14	.261	.391	5.0 G	5/6	1259
15	.289	.421	2.5 G	5/6	2150
16	.316	.454	10.0 GY	5/6	628

**Appendix E. Efficacy of Individual Plates in NSMRL version,
Dvorine set and Armed Forces Selection***

NSMRL Version	Dvorine Set	Armed Forces Selection
# 29 = 92.8%	# 74 = 94.1%	# 57 = 89.0%
# 47 = 92.4	# 62 = 93.3	# 42 = 84.2
# 56 = 91.7	# 46 = 91.5	(Orange) # 56 = 81.9
# 6 = 90.3	# 39 = 91.5	# 6 = 79.1
# 97 = 90.2	# 2 = 88.2	# 74 = 75.6
# 5 = 90.1	# 7 = 87.4	# 27 = 70.9
# 68 = 89.6	# 28 = 86.7	# 75 = 67.7
# 74 = 88.3	# 4 = 85.1	# 5 = 63.5
# 3 = 88.2	# 26 = 80.8	# 3 = 61.5
# 98 = 86.9	# 70 = 80.7	# 89 = 57.8
# 8 = 83.9	# 92 = 78.8	(Purple) # 56 = 52.9
# 25 = 82.4	# 95 = 77.7	# 47 = 52.1
# 27 = 75.7	# 38 = 70.0	# 15 = 33.8
# 42 = 73.0	# 67 = 65.0	# 86 = 33.6

*The percentage figure is based on percentage of color defectives failing the plate less the percentage of normals failing it.



Appendix F

Bausch & Lomb Slide No. 71-21-50 is a slide for binocular distance vision containing four pseudo-isochromatic plates - "5" ("2" to color defectives), "8" ("3" to color defectives), "56" ("58", "68", "66" allowed as alternate answers), and "27" ("22" allowed as an alternate answer). The score is the number of digits (not the number of plates) called correctly. A score of 5 or 6 indicates normal color vision; a score of 3 or 4, doubtful color vision (color defective or color normal with poor distance acuity); and a score of 0, 1, or 2, color defective.

This slide was administered to 145 protans, 166 deutans, and 25 normals. All subjects had normal distance acuity. Of the 145 protans, 142 were classified as color defective and 3 as color vision

doubtful. Of the 166 deutans, 152 were classified by this slide as color defective, 13 color vision doubtful, and 1 as color vision normal. Of the 25 normals, 11 were classified by this slide as color vision normal, 9 as color vision doubtful, and 5 as color defective.

The two reversible-number plates are ineffective for color defectives: The "5" was called "2" by only 3% and the "8" was called "3" by only 13%. The "5" was called "nothing" by 91% of the color defectives and evoked a normal response from 6%. The "8" evoked a normal response from 84% of the color defectives and was called "nothing" by 3%. The two other plates, despite all the alternate answers which are accepted as correct, are too difficult for normals: "56" was failed by 48% and "27" was failed by 64%.



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13. ABSTRACT

Color vision tests used by the different Departments and Agencies of the U. S. Government were evaluated and compared. The purpose was to determine the extent to which the different tests select and reject men with the same gradation of color vision defect.

Many color defectives of all types and degrees of defect and a smaller sample of normals were examined on the various tests and the results were compared with the results obtained by these subjects on the NSMRL Battery of Color Vision Tests for determining type and degree of defect. The NSMRL Battery was described and colorimetric specifications for all the tests used therein are given.

The tests were evaluated individually and comparisons between tests were made. They all showed some correlation between the degree of color vision defect and the performance score on the test. However, they ranged in their rejection of color defectives from a low of 12% to a high of 98%, and men with the same degree of defect have variable chances of being accepted for specific duties dependent on the test used.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Color vision requirements for the Armed Forces						
Pseudo-isochromatic plates and Lanterns						







